1. New cotton protection policy and rational use of pesticides

In cotton-producing regions of western Africa, cotton extension companies have, to some extent, lagged behind in their pest management programmes in recent years. These shifts in strategy, associated with economic constraints, could be detrimental to the environment and lead to the development of pesticide resistance in some cotton pests. Current know-how in this field is reviewed as a basis for recommendations on unscheduled treatments and on the optimal use of pesticides relative to agricultural and ecological needs.

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Cotton pests are a serious problem in cotton-growing regions of tropical Africa. They are responsible for losses of 40-60% in the cotton production potential, depending on the country and year, for mean yields of 1 000 kg/ha of seed cotton.

Pest management is therefore essential. There are two main regions, defined on the basis of climatic characteristics and the pests present (Table 1).

The use of chemical pesticides is still necessary. However, systematic prescheduled chemical control treatments, as currently carried out in all cotton-growing countries of tropical Africa, will no longer be possible over the short and medium term. Treatment decisions will be made on a "threshold" basis. Integrated pest management[1] offers a variety of alternatives to systematic chemical control.

1. Integrated pest management involves the combined and rational use of all available techniques to control various crop pests. The overall objective is to maintain pest populations below economically threatening levels.

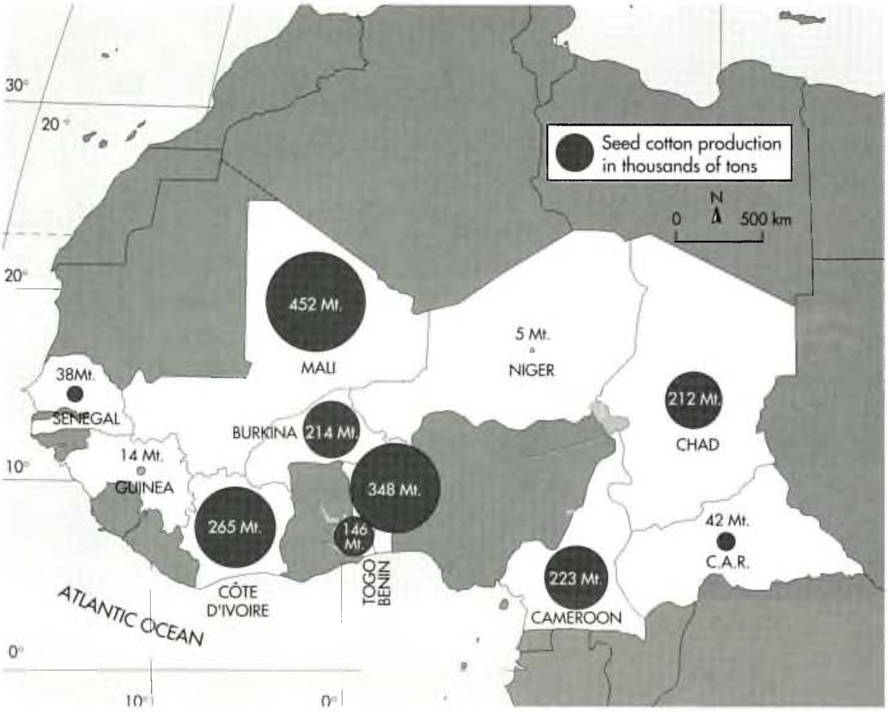


Figure 1. Cotton production in French-speaking countries of western and central Africa (Source: CFDT, 1997).

Table 1. Insect pests present in western and central African cotton-growing regions.

Region	Precipitation (mm)	Type of insects	Species
Northern zone	less than 1 000 to 1 100	sucking insects	*Jassidae* *Aphis gossypii* *Bemisia tabaci*
		leaf-eating caterpillars	*Syllepte derogata* *Anomis flava*
		boll weevils	*Helicoverpa armigera* *Diparopsis watersi* *Earias insulana*
		heteropterans	*Miridae*
Southern zone	more than 1 100	sucking insects	*Jassidae* *Aphis gossypii*
		spider mites	*Polyphagotarsonemus latus*
		leaf-eating caterpillars	*Syllepte derogata* *Spodoptera littoralis*
		exocarpal bollworms	*Helicoverpa armigera* *Diparopsis watersi* *Earias insulana* *Earias biplaga*
		endocarpal bollworms	*Cryptophlebia leucotreta* *Pectinophora gossypiella*

Treatment thresholds

Cotton pest management programmes were until quite recently designed to keep pest populations at low mean levels. Long-term economic impacts were estimated on the basis of results obtained on experimental plots comparing three levels of protection: untreated control, extension treatment, and maximum treatment.

Treatment programmes did not *a priori* take actual infestation intensities and types of pests into account. Prescheduled treatments of cotton crops were thus carried out during the flowering-fruiting phase, often every 14 days.

Alternative treatment programmes are now being implemented — they are not as costly and are adapted to real pest pressure levels. Treatments are therefore conducted when outbreak levels for one or several pests are high enough to cause harvest losses — this is the treatment threshold. In addition, treatment costs have to remain lower than economic losses that could be prompted by the outbreak.

Sampling assessments

Sampling is required to determine treatment thresholds, with all observations and counts noted on data sheets or peg-boards. The number of samplings required depends on the homogeneity of the plot. The general assessment procedure involves sampling 25 plants along a diagonal line transecting a unit plot (0.25-2 ha) on which a homogeneous cotton crop is grown.

Control results against the main cotton pests

Treatment thresholds against some pests have been determined on the basis of 10 years of field results: for exocarpal bollworms (worms that perforate the cotton boll but do not

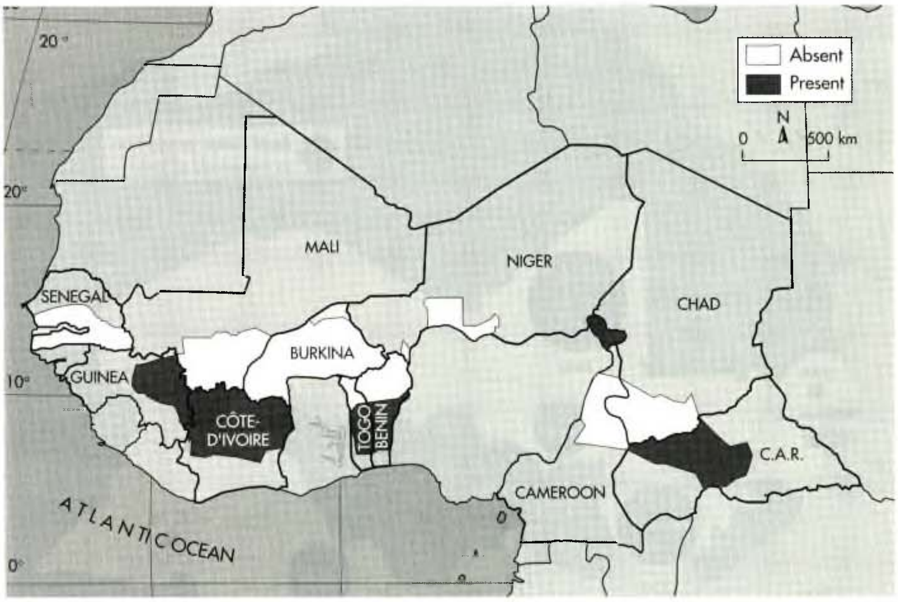
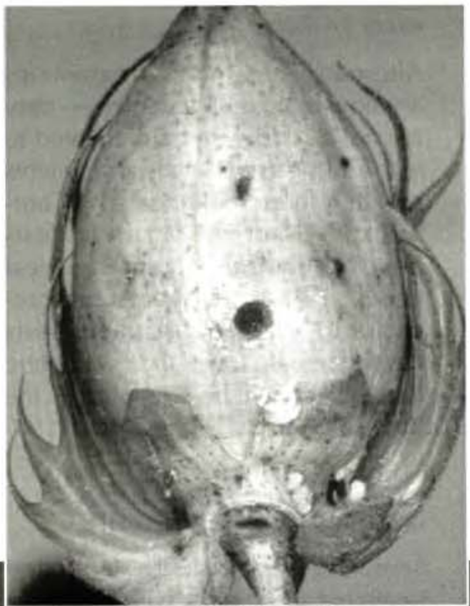


Figure 2. Endocarpal bollworm in different French-speaking countries of western and central Africa (Source: CIRAD, 1993).



C. *leucotreta* damages. Endocarpal bollworm (living inside the boll).

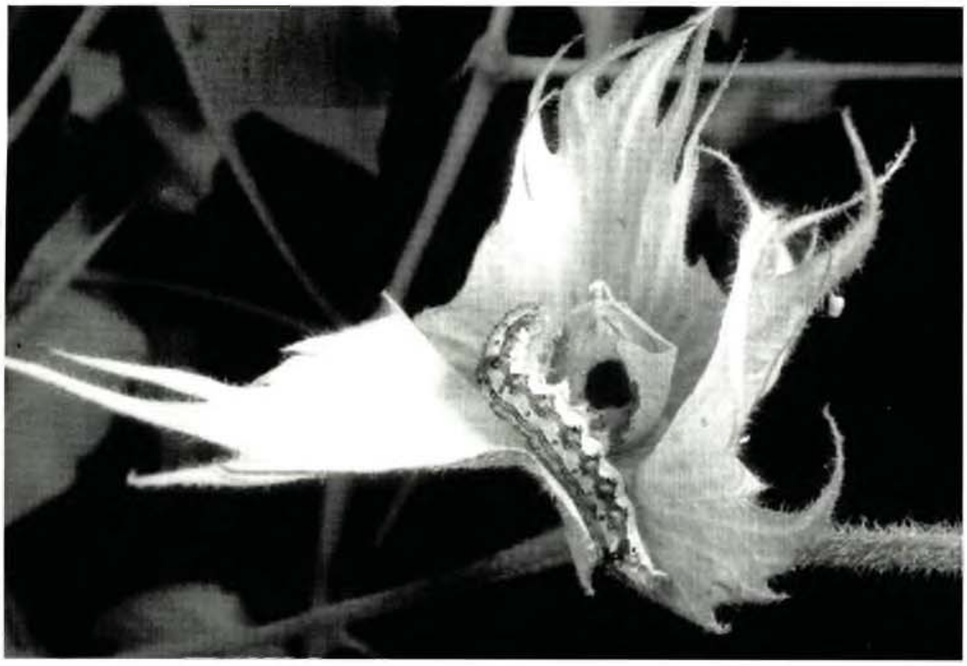
Photos CIRAD-UREA

inhabit the boll), leafeating caterpillars, and sucking insects. Spider mites are too small for easy counting, so treatment thresholds are set according to the observed extent of damage they cause.

It is very difficult to assess endocarpal bollworm (living inside cotton bolls) infestation levels. The cotton bolls have to be opened to count *Pectinophora gossypiella* Saund. and *Cryptophlebia leucotreta* Meyr. larvae populations. These pests are distributed over a quite wide area in western Africa, i.e. 300 000-350 000 ha out of 1 million ha that are treated (Figure 2).

Treatment threshold estimates are not always very accurate. Several treatment thresholds could be proposed for many pests during the outbreak phase. The time it takes to reach the threshold is also an important factor, e.g. with spider mites, leaf-eating caterpillars and even the American bollworm *Helicoverpa armigera* Hbn.

It is more difficult to make treatment decisions when several different pest species are present and none of them have reached their respective thresholds. A cumulative or multiple threshold concept should thus be introduced.



Exocarpal bollworm (living outside the boll) *Helicoverpa armigera*.
Photo CIRAD-UREA

Advantages of treatment thresholds

With a treatment threshold, treatments can often be undertaken when the pest is at an especially susceptible development stage, e.g. recently hatched worms. Pesticides, acting as a function of the insects' weigh have higher efficacy and they can be applied at lower doses than those used in preventive treatments. The success of a pesticide treatment also depends on how early the treatment is carried out, using an active ingredient specific to the target pest.

An adapted and reliable choice of active ingredients

The efficacy and quality of pesticide formulations

The efficacy of a pesticide for controlling a pest or a group of insects is obviously an important consideration, but its harmfulness is also important, i.e. risk of intoxicating vertebrates, and environmental impact, especially on nontarget wildlife.

It is also essential to assess the risk of losing efficacy through pesticide resistance. This resistance can develop through various mechanisms (in the nervous system, digestive system, etc.), at very few known target sites in the insect for the main pesticide families: pyrethroid, organochlorine (including DDT), organophosphorous and carbamate compounds. When resistance to a pesticide develops at a target site, then the efficacy of other active ingredients in the same family can be nullified. New groups of active ingredients with different target sites should thus be developed.

The quality of proposed formulations should also be monitored. The presence of impurities in the active ingredient or solvents can lower the efficacy of a pesticide against a target insect. Solvents can modify the toxicity of the formulation to the user and affect the material of the pesticide container (i.e. varnishes coating the inside of the container have to be solvent-resistant).

Active ingredient contents and their origins should thus be controlled for all marketed pesticides.

Pesticide formulations could be concentrated in order to limit shipping and handling costs, but this increases the risk of dosage errors. The danger of intoxication during field handling should also be taken into account.

Guidelines published by the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) confirmed the grounds of restrictions on the use of organochlorine pesticides. In 1984, they were withdrawn for use in cotton in French-speaking Africa.

Pesticides used for seed treatments have a special status as they have very little environmental impact and their formulations differ from those of compounds used in foliar treatments. Nevertheless, other chemical families are now being proposed for treatments involving new techniques.

Table 2. List of active ingredients classified on the basis of their toxicity levels (Source: International Programme on Chemical Safety, the WHO recommended classification of pesticides by hazard and guidelines to classification 1992-1993, WHO/PCS/92-14).

Toxicity	Active ingredient	Pesticide
Class 1a **extremely hazardous**	aldicarb	carbamate
	disulfoton	organophosphate
	mevinphos	organophosphate
	parathion-methyl	organophosphate
	phosphamidon	organophosphate
Class 1b **very hazardous**	aldrin	organochlorine
	azinphos-methyl	organophosphate
	benfuracarb	carbamate
	carbofuran	carbamate
	dieldrin	organochlorine
	endrin	organochlorine
	flucythrinate	pyrethroid
	furathiocarb	carbamate
	isazophos	organophosphate
	isoxathion	organophosphate
	methamidophos	organophosphate
	methomyl	carbamate
	monocrotophos	organophosphate
	nicotin	-
	omethoat	organophosphate
	triazophos	organophosphate
Class 2 **moderately hazardous**	bifenthrin	pyrethroid
	carbaryl	carbamate
	carbosulfan	carbamate
	chlopyrifos	organophosphate
	cyflutrin	pyrethroid
	lambda cyhalothrin	pyrethroid
	alpha cypermethrin	pyrethroid
	cypermethrin	pyrethroid
	DDT	organochlorine
	deltamethrin	pyrethroid
	dimethoate	organophosphate
	endosulfan	organochlorine
	esfenvalerate	pyrethroid
	fenpropathrin	pyrethroid
	fenvalerate	pyrethroid
	fluvalinate	pyrethroid
	BCH	organochlorine
	gamma-BCH (lindane)	organochlorine
	methiocarb	carbamate
	permethrin	pyrethroid
	phosalone	organophosphate
	profenofos	organophosphate
	thiodicarbe	carbamate
	tralomethrine	pyrethroid
Class 3 **slightly hazardous**	acephate	organophosphate
	amitraz	formamidine
	dicofol	carbinol

Endosulfan is a special organochlorine compound. It is generally considered acceptable for pesticide treatments, especially against lepidopterans that have developed resistance to some other pesticides. The target site of endosulfan is not the same as that of pyrethroids.

Concerning organophosphorous and carbamate pesticides, all active ingredients classified as "extremely dangerous (1a)" and "very dangerous (1b)" by WHO (based on the theoretical toxicity of the active ingredients, Table 2), should gradually be withdrawn from the recommended list, despite the excellent activity of some of these compounds.

Users should assess the toxicity of a pesticide both in terms of its active ingredient and spraying conditions in the field, i.e. the formulation (solvent and compound levels) and dosage.

Pesticide specificity and use

Active ingredients are generally chosen according to defined targets. The main pest groups are spider mites, sucking insects, leaf-eating lepidoptera, bollworms, and bugs. Specific active ingredients are very important for threshold treatments. In fact, the active ingredient choice should take the impact on nontarget fauna, including pests considered to be of secondary importance at the time of treatment and beneficial organisms (predators and parasitoids).

Mixtures of some products can produce "potentiation" , i.e. the pesticide activity of a blend of two compounds can be better than the sum of the activities of the two products used separately. This association can help prevent the development of resistance to an active ingredient or to a family of chemicals because of the different target sites of the two active ingredients involved. The pest management consultant and farmer often end up spraying crops with binary mixtures that are not specific to the target pest, particularly when pyrethroids are used. These pesti-

Colony of aphids.
Photos CIRAD-UREA

cides are thus sprayed at low doses, which can lead to considerable economic savings.

Another strategy that can limit the development of pesticide resistance in pests involves alternating treatments, using active ingredients with target sites that differ from those of pyrethroids, i.e. endosulfan, carbamates and organophosphorous compounds. This alternation can be done on a per-year basis — a pattern used for acaricide treatments in Zimbabwe — or within the same campaign, while limiting the use of pyrethroids during the fruiting cycle, as carried out in Australia.

Initial results obtained in western Africa highlight the interest of applying two endosulfan treatments at the onset of the crop season. This technique is efficient against spider mites, sucking insects and *H. armigera* in low to moderate outbreak situations. However, this active ingredient is inefficient in controlling *Diparopsis watersi* (northern hemisphere) or *D. castanea* (southern hemisphere). Outbreaks of these pests should thus be closely monitored, with the possibility of conducting additional treatments.

Rational doses and frequency of treatments

Fully adapted treatment techniques, pesticide supplies and observations are necessary when changing from prescheduled treatments to a threshold treatment scheme.

Farmers require a considerable amount of technical training to be able to follow up a sampling programme and identify the main cotton pests. In terms of logistics, users should have access to different, easily-identifiable and mixable formulations, for quick specific responses to any pest outbreak.

Economically, it is essential to be able to provide the price of each treatment upon request — a very recent feature in tropical Africa — and to constantly reassess the cost-effectiveness of each treatment relative to potential harvest losses.

Transition pest management programmes

To overcome these constraints, in recent years the cotton research programme has been proposing pest management programmes with progressive integration of threshold treatments (Figure 3). These programmes will be described in the next article.

The general recommendations are as follows:

– systematic low-dose pest control, combining pesticide savings and farmers' safety with the efficacy of treatments and prevention of pesticide resistance;

– surveying pest levels, which could lead to postponement of a scheduled treatment, or to a decision to carry out an additional treatment.

Traditional treatments

5-6 prescheduled treatments every 14 days after 42-45 days of vegetative development, involving ultra low volume spraying (1-3 l/ha of solution) with a ready-to-use pyrethroid/organophosphorous compound mixture.

New treatment technique
VLV spraying of water-based formulations (10 l/ha of solution)

– with binary ready-to-use formulations (see previous case);
– or with adapted active ingredient doses that are sprayed separately.

Transition programme
"Staggered-targeted control"

– 1st step: six half-dose treatments, six observations and, if necessary, an additional dose of active ingredient is used for the 14th day treatment;
– 2nd step: six half-dose treatments, six observations, an additional treatment 8 days after the previous one, if necessary. The most restrictive method, but closer to threshold treatments.

Threshold treatments

A switch to threshold treatments is much more difficult in areas infested with endocarpal bollworms, as they are not easy to count.

New pest protection programme
"Integrated pest management"

Integrated pest management takes all control alternatives into consideration: choice of crop varieties, entomophagous and entomopathogenic (*Bacillus thuringiensis*, etc.) organisms, trap crops, etc.

Figure 3. Transition from standard prescheduled treatments to integrated pest management.

The threshold treatment technique is primarily used to control the main pests such as spider mites and leaf-eating caterpillars, sucking insects and bollworms. Active ingredients (pyrethroids, organophosphorous and carbamate compounds) are chosen on the basis of the target insects:

– against bollworms, pyrethroids are used at low dose, preferably in conjunction with an organophosphorous compound (also at low dose) with potentiation activity;

– against leaf-eating caterpillars and mites, some organophosphorous compounds are efficient;

– against sucking insects, organophosphorous and carbamate compounds are used.

In practice, the same organophosphorous active ingredient is often used to control spider mites and leaf-eating caterpillars, with a potentiation effect in mixtures with pyrethroids. However, aphicides and aleurodicides are often specific, and their activities are not enhanced when mixed with other active ingredients. With endocarpal bollworms, especially in regions where *C. leucotreta* is common, prescheduled treatments are still recommended.

Pest population assessments should be conducted at least once a week.The frequency of pesticide treatments is very important. A low dose treatment should be carried out as soon as possible (within 48 h) after a treatment decision has been made, in order to optimize successive treatments. When serious outbreaks occur, two staggered treatments at normal doses are better than a single treatment with a double dose.

Although farmers generally handle pest outbreak situations in an empirical manner, the volume of the pesticide mixture should be adjusted with respect to the vegetative development stage of the cotton crop. For all treatment techniques, the first two treatments can be carried out with low pesticide volumes. At the onset of vegetative development, each treatment run is faster and pesticide quantities applied per unit area are lower, regardless of the spraying volume. Conversely, at the end of the development cycle, a higher volume has to be sprayed because of the higher vegetation mass in the cotton plantation, which can hamper spraying operations. Changes in the spraying volume have a direct effect on the active ingredient quantities applied.

An example of adapted pesticide treatments in Côte d'Ivoire

Pesticide active ingredient doses are calculated in terms of the type and level of infestation. The type of pesticide to be used is chosen in terms of the level of risk related to the agricultural practices used on the plot.

The kind of parasitism is determined by the following factors: the presence of spider mites (*Polyphagotarsonemus latus* Banks) in the centre of the country; outbreaks of sucking insects (mainly the whitefly, *Bemisia tabaci* Gennadius) at the end of the cotton crop season in the north; and the presence of endocarpal bollworms *(C. leucotreta)* in the south.

Figure 4. The different types of spraying equipment used for cotton pest management.
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From left to right:
– high-pressure knapsack sprayers fitted with a horizontal "cadou" spraying bar with four nozzles (for spraying two rows at once);
– Berthoud C8 ULV sprayer;
– Ulvaplus VLV Micronsprayer;
– Berthoud C4-10 VLV sprayer.

Recommended treatments systematically include a pyrethroid/organophosphate mixture, e.g. cypermethrin mixed with profenofos or dimethoate.

Training farmers on new treatment techniques

Research studies on active ingredients with very high efficacy will not be useful unless efficient treatment techniques are available.

In western Africa, pest management programmes began being developed in the 1960s, with knapsack sprayers fitted with a horizontal spraying bar (Figure 4) for the treatment of two rows of cotton plants. About 80-100 l/ha of pesticide mixture can be sprayed with this equipment. In the 1970s, constraints in organizing field treatments along with water shortages at the end of the crop season, prompted the introduction of hand-held rotary disk sprayers. These were used for ultra low volume (ULV) spraying of one in every five to six rows (1-3 l/ha), with ready-to-use oil-based formulations.

This spraying equipment is currently used for very low volume (VLV) treatments with water-based formulations. The spraying volume has been set at 10 l/ha of water emulsion, thus accounting for formulation and spraying constraints. It is essential to be able to use emulsifiable or soluble concentrates for specific control purposes, while adapting dosages to the prevailing level of parasite pressure.

The following possibilities are therefore open to farmers: choosing one or more pesticides for each treatment; adjusting the active ingredient dose; and avoiding spraying drift during pesticide treatments. However, this is still only a compromise technique. It has some drawbacks, including longer treatment times and the need to handle concentrated formulations. It is of considerable interest to have these many different treatment techniques available for setting up new pest management programmes.

Conclusion

There has been a recent irreversible change in cotton pest management programmes in western and central Africa. This will eventually lead to the adoption of threshold treatments. Chemical treatments will be conducted only when necessary during cotton growth phases.

Different steps are planned to facilitate the transition between traditional pest protection practices and *sensus-tricto* treatment thresholds. The aim is to train control operators and to limit risks involved in the replacement of prescheduled treatment programmes. Everyone participating in cotton pest control is concerned, including staff of extension companies that deal with farmers, observers (from villagers' organizations), scouts responsible for field counts, and even farmers.

Main pests

Adult colony of *Bemisia tabacci*.
Photo CIRAD-UREA

Colony of *Aphis gossypii*.
Photo CIRAD-UREA

Helicoverpa armigera on a boll.
Photo CIRAD UREA

Cryptophlebia leucotreta on a boll.
Photo CIRAD-UREA

Diparopsis watersi on a boll.
Photo CIRAD-UREA

Pectinophora gossypiella on a boll.
Photo CIRAD-UREA